A Variability Study of Ka-Band HRR Polarimetric Signatures on Eleven T–72 Tanks

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Abstract

In an effort to effectively understand signature verification requirements through the variability of a structure's RCS characteristics, the U.S. Army National Ground Intelligence Center(NGIC), with technical support from STL, originated a signature project plan to obtain MMW signatures from multiple similar tanks. In implementing this plan NGIC/STL directed and sponsored turntable measurements performed by the U.S. Army Research Laboratory(ARL) Sensors and Electromagnetic Resource Directorate on eleven T-72 tanks using an HRR full-polarimetric Ka-band radar.[1] The physical condition and configuration of these vehicles were documented by careful inspection and then photographed during the acquisition sequence at 45° azimuth intervals. The turntable signature of one vehicle was acquired eight times over the three day signatures acquisition period for establishing measurement variability on any single target. At several intervals between target measurements, the turntable signature of a 30 m^2 trihedral was also acquired as a calibration reference for the signature library. Through an RCS goodness-of-fit correlation and ISAR comparison study, the signature–to–signature variability was evaluated for the eighteen HRR turntable measurements of the T-72 tanks. This signature data is available from NGIC on request for Government Agencies and Government Contractors with an established need-to-know.

Keywords: T-72, tank, HRR, Polarimetric, RCS, ISAR, Ka-Band, Nearfield, Turntable, Radar, Signature, Correlation

1. Signature Measurements and Comparison Methods

Using the ground level turntable at Aberdeen Proving Ground's Air Base Range 8, ARL's 8.5° beamwidth Ka-band radar was positioned on a lift 153 feet from the turntable's center of rotation achieving

a 5° elevation. Anechoic material was placed on the turntable around each vehicle to minimize ground-to-target interactions. An in-scene trihedral was located in front of the turntable enabling monitoring of the range profile's sweep-to-sweep amplitude continuity and phase stability. By turning the radar toward an array of simple shape calibration objects (located left of the turntable), range equivalent measurements acquired, before and after each turntable measurement, on a trihedral and dihedral at three seam orientations acted as a calibration for performing a full-polarimetric I,Q signature correction.[2] Signature data was also vector-background-subtracted using periodic sky directed signature measurements of the system related background.

The signatures acquired over the three day acquisition period have been listed in Table 1 by vehicle bumper # and signature file designation. During the quantification of signature-to-signature variations, an automated signature realignment procedure was created as part of the TRCS and ISAR analysis/correlation software. Borne from these realignment procedures was an azimuth correction value for each of the turntable measurements relative to tgt47au. While any one of the eighteen signatures would have served as the relative standard, file tgt47au was chosen as the alignment standard simply because its azimuth dependent RCS signature exhibited the best peak alignment to the four cardinal points.

Table 1. Acquisition of the T-72 Tank Signature Data

Day	Time	bumper #	file desig.	azimuth correction
Aug 3	<8:46	115	tgt47ag	-1.8
" "	09:04	115	tgt47am	-1.9
" "	09:10	115	tgt47an	-1.9
" "	10:12	000	tgt47au	std.
" "	11:06	185	tgt47ba	-1.2
" "	18.28	124	tgt47bn	-0.4
" "	20:50	758	tgt47bu	+1.4
" "	22:00	115	tgt47cb	+1.4
Aug 4	<8:20	115	tgt47cn	-0.7
" "	<8:20	115	tgt47ct	-1.3
" "	09:29	197	tgt47da	-1.1
" "	10:15	130	tgt47db	-1.5
" "	11:00	131	tgt47di	-1.6
" "	12:00	162	tgt47do	-1.5
" "	01:30	115	tgt47dv	+1.4
Aug 8		292	tgt47fo	-0.9
" "		343	tgt47gb	-2.0
" "		115	tgt47gc	+0.6

The signature-to-signature RCS variability was quantified using a methodology originally developed for comparing signatures (and establishing similitude) between MMW field data and scaled submillimeter-wave compact range turntable measurements.[3] The four level procedure has been expressed in an order of increasing rigor by the following:

Level 1. Statistical evaluation of frequency and/or azimuth averaged signature data. (For

example, evaluating the correlation between means, medians and RCS probability distribution curves.)

Level 2. Identification of generalized features for frequency and azimuth averaged RCS values as a function of target look angle through performing a goodness-of-fit cross-correlation of the signature library.

Level 3. Visual inspection of RCS specific characteristics on ISAR signatures at comparative look angles accounting for obvious pose differences using signature sequenced photography along with an on-site inspection report of the vehicles.

and

Level 4. Detailed analytical point-to-point RCS comparison of sampled ISAR imagery by way of performing a goodness-of-fit cross-correlation of the signature library.

2. The Signature Data

The signature data for the eighteen HRR turntable measurements of the T-72 tanks are available from NGIC on request by Government Agencies and Government Contractors with an established need-to-know. The user may request the signature data in any one of the following three file formats:

1. ARL's 100 MB full-polarimetric uncalibrated signature file for each turntable measurement. Calibration and background signatures reside as separate files.

2. NGIC Labview™-based ASCII formatted files of calibrated signature data (without enhancement) of the target with inscene calibrator, array of simple shape calibration objects and sky directed radar. Data is structured and flagged as detailed in Table 2.

3. NGIC Labview™-based ASCII formatted files of fully calibrated signature data with background subtraction and in-scene stationary scatterers eliminated.

Labview-based software has been generated for in-house calibration, processing and analysis of the Ka-Band turntable signature data described in this report. The program is designed to execute signature file I/O and a TRCS, HRR and/or ISAR analysis, as well as the type of file storage and data processing techniques; such as background subtraction, polarimetric calibration, image/profile sizing, thresholding and/or averaging.

Initially the 100 MB full-polarimetric uncalibrated signature file for a target turntable measurement is read and its file storage is reformatted for compatibility with NGIC/STL's Labview™-based analysis software. With an ASCII header describing the radar and target configuration, the original turntable data is stored in binary format as 512-byte records representing the 256 frequency-dependent (16-bit) A/D voltage reading of either the in-phase receive channel (I) or the sequential data array representing its quadrature receive channel (Q). The VV I,Q pairs of data arrays for the entire spin, at ≈0.015° azimuth resolution, has been recorded and is then followed by the VH, HV and finally HH transmit-receive polarization data. Measurements of the calibration objects reside as separate files. This file organization necessitates formation of four 25 MB integer-format temporary storage files, one for each transmit-receive polarization signature set, since NGIC/STL's analysis acts on the four transmit-receive polarization channels for each look angle simultaneously.

Responsible for reorganization of the original turntable signature file, an NGIC/STL subprogram reads the four temporary files along with the Ka-Band signature measurements of the four-object calibration array and sky (background), five separate files, and stores the measurements as a single ASCII data file. Reflected in table 2 is the record format of the Labview™-based data log file generated making the signature storage compatible with NGIC/STL's SMS analysis software. Signal analysis enhancement techniques specific to the type of signature output; i.e. TRCS, HHR or ISAR, are implemented in their respective subprograms.

Table 2. Labview™-based Data Log Record Format/Definition

U32,U16,I32,SGL,{SGL},{SGL},{SGL},{SGL},{SGL},{SGL},{SGL},{SGL},abc

U32,U16 - time stamp

I32 - data type

0 = signature data
2 = 0°, or 90°, dihedral
3 = 45° dihedral
4 = trihedral
5 = 22.5° dihedral
7 = background/sky
9 = error

SGL - theoretical radar cross section of the calibration objects in units of m^2.

{SGL},{SGL},{SGL},{SGL},{SGL},{SGL},{SGL},{SGL} - the eight one-dimensional single precision data arrays containing the full-polarimetric in-phase and quadrature receive voltages; Ivv, Qvv, Ivh, Qvh, Ihv, Qhv, Ihh, Qhh.

abc - description of preceding data line, character format

3. Evaluation of the T-72 Tank Signature Data

The methodology described was executed on the signature data by performing level 1 comparisons between the eighteen signatures acquired on the eleven T-72s, nine T-72/M1s and two T-72/Bs. Initially,

the arithmetic mean, standard deviation and median of the azimuth averaged RCS turntable data were calculated for each signature as shown in Tables 3, 4 and 5. Achieving average mean and median values of 12.7 dBsm and 11.3 dBsm for the eight VV signatures acquired on a single T-72/M1, this data exhibited a maximum difference between the values of only 0.6 dB and 0.7 dB, indicative of the system's measurement variation. The average mean and median values of 12.9 dBsm and 11.6 dBsm for the VV signatures acquired on the nine T-72/M1s with similar configurations exhibited a maximum difference between the values of 1.6 dB and 1.5 dB, indicative of target configuration differences.

Table 3. The Ka-Band RCS (dBsm) Statistics for Eight Signatures of the same T-72/M1

VV				HH		
MEAN	**STD.DEV.**	**MEDIAN**	**Measurement**	**MEAN**	**STD.DEV.**	**MEDIAN**
12.40	11.91	11.08	AG	13.05	12.58	11.71
12.38	11.95	11.02	AM	13.05	12.57	11.69
12.53	12.05	11.24	AN	13.14	12.55	11.64
12.99	12.49	11.73	CB	13.69	13.51	12.02
12.79	12.46	11.46	CN	12.81	12.47	11.37
12.63	11.96	11.21	CT	12.64	12.37	11.14
12.78	12.41	11.22	DV	12.91	12.96	11.29
12.79	13.12	11.16	GC	12.90	12.72	11.41
12.67	**12.31**	**11.27**	**AVERAGE**	**13.03**	**12.73**	**11.54**

Table 4. The Ka-Band RCS (dBsm) Statistics for Signatures of Nine Similar T-72/M1s

VV				HH		
MEAN	**STD.DEV.**	**MEDIAN**	**Measurement**	**MEAN**	**STD.DEV.**	**MEDIAN**
12.40	11.91	11.08	AG	13.05	12.58	11.71
12.34	12.50	10.68	AU	12.52	12.53	11.11
12.12	11.39	10.93	BA	13.07	13.13	11.57
13.53	13.59	12.26	BN	13.90	14.61	12.30
13.23	13.16	11.89	BU	14.00	13.92	12.64
13.70	14.49	12.25	DA	14.66	15.01	13.28
12.63	11.81	11.35	DB	13.34	12.80	12.04
13.07	11.50	12.10	DI	13.33	12.11	12.21
13.36	15.09	11.71	DO	13.40	13.80	12.06
12.96	**13.02**	**11.62**	**AVERAGE**	**13.52**	**13.49**	**12.14**

Table 5. The Ka-Band RCS (dBsm) Statistics for Signatures of T-72/Bs with and without armor.

VV				HH		
MEAN	**STD.DEV.**	**MEDIAN**	**Measurement**	**MEAN**	**STD.DEV.**	**MEDIAN**
14.21	13.72	13.00	FO	14.80	14.87	13.31
14.40	14.86	13.31	GB	14.62	14.88	13.32

It may be concluded that the differences in target configurations measured using ARL's Ka-band radar caused observable changes in the T-72/M1's signature since the mean and median of the nine configurations exhibit a maximum difference greater than the difference exhibited by the system's measurement variation. These differences may be considered minimal and it is expected that a robust

detection/recognition algorithm (or autonomous target recognizer, ATR) will accept these signatures as typical variations since the average VV mean and median values from the nine configurations differ from the eight signature values only by 0.2 dB and 0.3 dB, less than the system's measurement variation. However, the signature identified as GB represents a turntable measurement of the T-72/B with reactive armor while FO is a signature of the T-72/B with the reactive armor's brackets only. Since the values of the mean and median for these vehicles fell 2 dB above the nine target average (See Table 5.), approaching these signatures with the same ATR mask, generated for detecting or recognizing the T-72/M1s will probably be challenging and likely cause an increase in false alarms.

Figures 1 through 3, the first component of a level 2 signature comparison, represent overlays of the RCS signature versus azimuth averaged over a 1° window for display purposes. Upon recognizing the azimuthal signature alignment assigned during the acquisition sequence was suspect, an autorotation feature was implemented when calculating the goodness-of-fit least-square-mean correlation error between 4000 pt. signatures[1], the second component of the level 2 signature comparison. By iteratively adjusting (sliding) each target's azimuth dependent RCS signature relative to the same reference signature (measurement AU was chosen), the misalignment between signatures was reduced from a 3.5° spread to less than ±0.09° by minimizing the least square mean error for the RCS signature displays and correlation study. With the angular difference a function of the entire 360° target sweep, the values calculated (listed in Table 1) were used as a reference when comparing ISAR images.

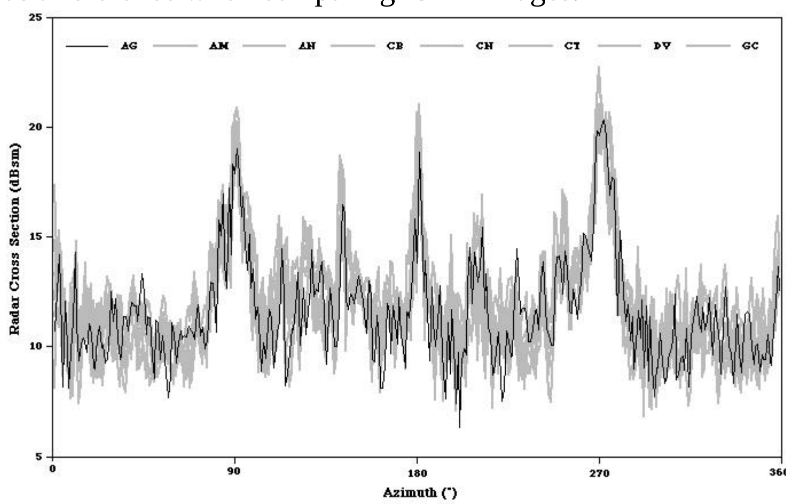

Figure 1. The Ka-Band VV RCS for Eight Signatures of a T-72/M1 (Bumper #115)

[1]With a sweep resolution of 0.015°, the RCS signature data, center frequency only, was azimuth averaged with a 6 point sliding window to 0.09° creating a 4000 point signature representation of each turntable measurement.

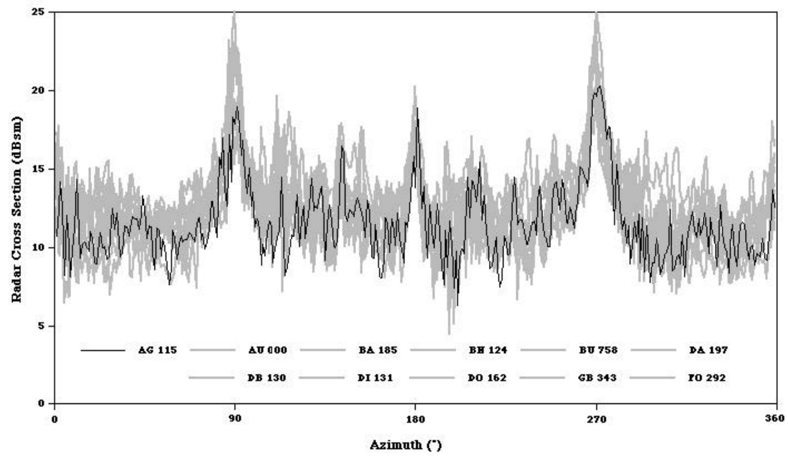

Figure 2. The Ka-Band VV RCS of the Eleven T-72s with the Reference Vehicle's Signature Highlighted.

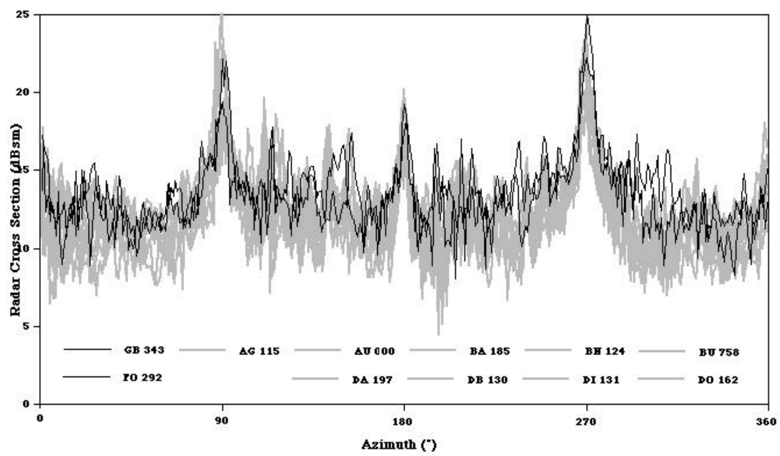

Figure 3. The Ka-Band VV RCS Signatures of the Eleven T-72s Measured.

Tables 6, 7 and 8 summarize the goodness-of-fit total RCS signature correlation study. The average difference values provide a measure of the average vertical distance, difference in angular dependent RCS, between target signatures. Achieving an average value of 1.58 dB for the eight VV signatures acquired on a single T-72M1 (indicative of the system's measurement variation - an average of all the values expressed in Table 6), while obtaining a value of 1.95 dB for the nine VV signatures of the individual T-72 vehicles (an average of all the values expressed in Table 7) implies observable signature differences between the T-72s in this signature set.

Table 6. The Ka-Band VV RCS (dB) Signature-to-Signature Comparisons for the Eight Measurements of a T-72

	AG vs.							
AM	1.38	**AM vs.**						
AN	1.37	0.57	**AN vs.**					
CB	1.61	1.64	1.56	**CB vs.**				
CN	1.64	1.73	1.71	1.57	**CN vs.**			
CT	1.64	1.75	1.72	1.67	1.51	**CT vs.**		
DV	1.61	1.67	1.61	1.58	1.55	1.50	**DV vs.**	
GC	1.73	1.70	1.97	1.56	1.51	1.50	1.53	**GC vs.**
AVERAGE	1.57	1.51	1.52	1.60	1.60	1.61	1.58	1.65

Table 7. The Ka-Band VV RCS (dB) Signature-to-Signature Comparisons for the Measurements of Nine T-72/M1s

	AG vs.								
AU	1.84	**AU vs.**							
BA	1.88	1.86	**BA vs.**						
BN	2.06	2.10	2.10	**BN vs.**					
BU	1.94	2.03	2.02	1.80	**BU vs.**				
DA	2.04	2.24	2.18	1.91	1.92	**DA vs.**			
DB	1.89	1.99	1.99	2.06	1.93	2.20	**DB vs.**		
DI	1.85	2.07	1.94	1.76	1.82	1.89	1.97	**DI vs.**	
DO	1.82	1.92	1.85	1.84	1.87	1.83	1.88	1.78	**DO vs.**
AVERAGE	1.92	2.01	1.98	1.96	1.92	2.03	1.99	1.89	1.85

Table 8. The Ka-Band VV RCS (dB) Signature-to-Signature Comparisons between the T-72/M1s and two T-72/Bs

	AG vs.	AU vs.	BA vs.	BN vs.	BU vs.	DA vs.	DB vs.	DI vs.	DO vs.
FO	2.37	2.49	2.51	1.94	2.01	2.08	2.33	2.02	2.19
GB	2.54	2.69	2.64	2.23	2.16	2.21	2.55	2.22	2.31

By comparing the statistical differences between FO, or GB, (the row averages of Table 8) and the other nine target configurations, one will notice that the values are consistently higher which also implies observable differences between the T-72/Bs and T-72/M1s evaluated using this signature library. An average signature-to-signature variation of 1.83 dB between FO and GB (typical of the values expressed in Table 7) indicates the configuration differences between the two T–72/Bs are equivalent to those difference between the T-72/M1s from the perspective of the signature data.

For the sake of brevity, the preceding arguments were based on tabulated statistical comparisons of only the T-72's VV signature data. The average difference between any two signatures for each of the

remaining three transmit/receive polarizations were also extensively investigated and the results supported arguments similar to the preceding discussions.

Table 9. Observed Differences in Condition and Configuration of the Nine T-72/M1s.[2]

	Vehicle designation-Bumper#	115	000	185	124	758	197	130	131	162
	Comments			early model T-72		no photos	parade condition			
1	radiator exhaust covers (rear)						covers up			
2	machine gun turret topside		turret rotated 180°				with ammo box			
3	extra fuel barrels									
4	whip on antenna mount				8"stub					
5	front tow cable					no photos				
6	ammo boxes, passenger side turret								also no brackets	
7	unditching log									
8	machine gun cover /main barrel									
9	machine gun mount		front facing							
10	spotlight, driver's side turret		rear facing							
11	smoke grenade launchers				1 uncapped					
12	fuel tank skirts									
13	side skirts		1 uncoupled	6" overhang						
14	tow cable (rear)									hanging
15	headlight passengers side		lens broken out							
16	central utility box on rear of turret					no photos				
17	infrared sensor, metal cover									
18	fuel barrel racks			1 bent rib	1 bent rib				2 bent ribs	with 3 plates
19	spare track links, rear		1 missing	2 missing		no photos				
20	snorkel & canvas roll		cover is bent	cover is bent	no canvas roll	no canvas roll				
21	small cable brackets		1 missing	1 missing	0 2 missing	1 missing				
22	front track cowlings with ridges	bent	bent	bent	no ridges/bent	bent				
23	main gun barrel cap	torn cowling	canvas					duct tape	duct tape	duct tape
24	front splash panels	bent	bent	bent up	bent	bent up	bent	dented	dented	dented

Equipment Description	intact	missing

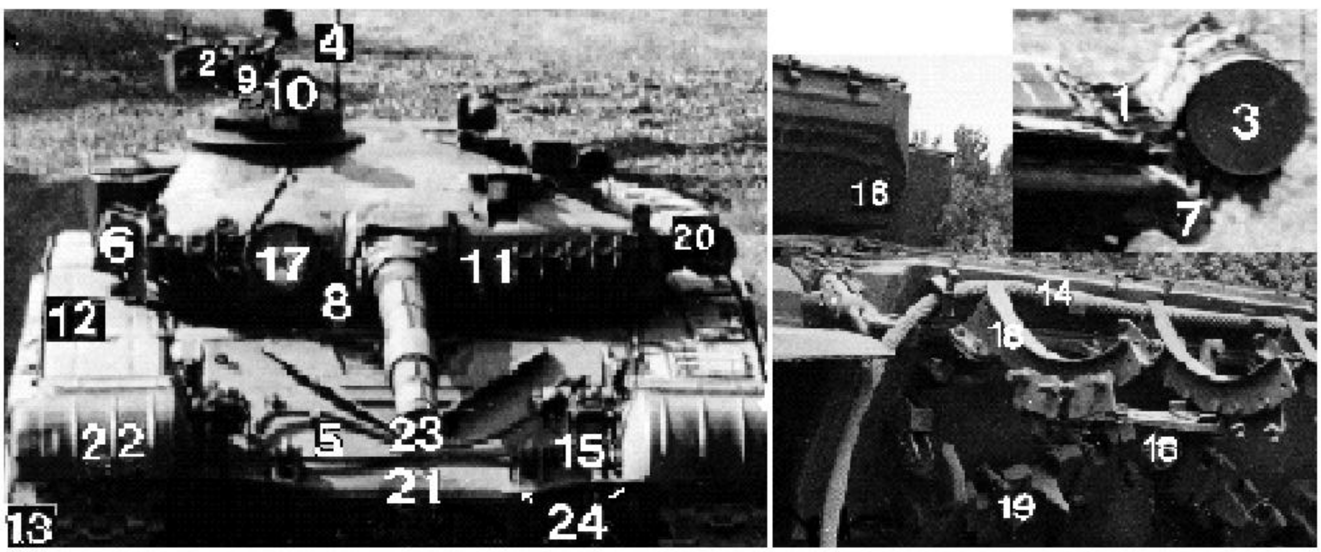

Figure 4. Visual Identification of the T-72's Equipment.

By analysis of the statistical RCS correlation study, in consideration of known variations in vehicle condition, the azimuthal range of angles from 240° through 250° were chosen for further investigation using the 3rd comparative level of signature evaluation. The observed differences in target configuration and physical condition identified in the on-site inspection report of the nine T-72/M1s have been detailed in Table 9 and Figure 4. To allow for visual inspection of RCS specific characteristics for the T-72s individual scatterers in these specific regions, ISAR images representing the four transmit/receive polarizations were produced at comparative azimuth angles accounting for obvious pose differences using signature sequenced photography and the azimuth correction factor calculated during the level 2 goodness-

[2]No configurational studies were recorded for the vehicles with bumper #292 and 343 other than those discussed in the text.

of-fit signature correlation study. With the radar's operational center frequency of 34.25 GHz and bandwidth of 1511.64 MHz, a 3 inch range/cross-range resolution and 64' unambiguous range (256 steps across the BW) was achieved when processing the T-72s RCS-color-calibrated ISAR images as shown in Figure 5.

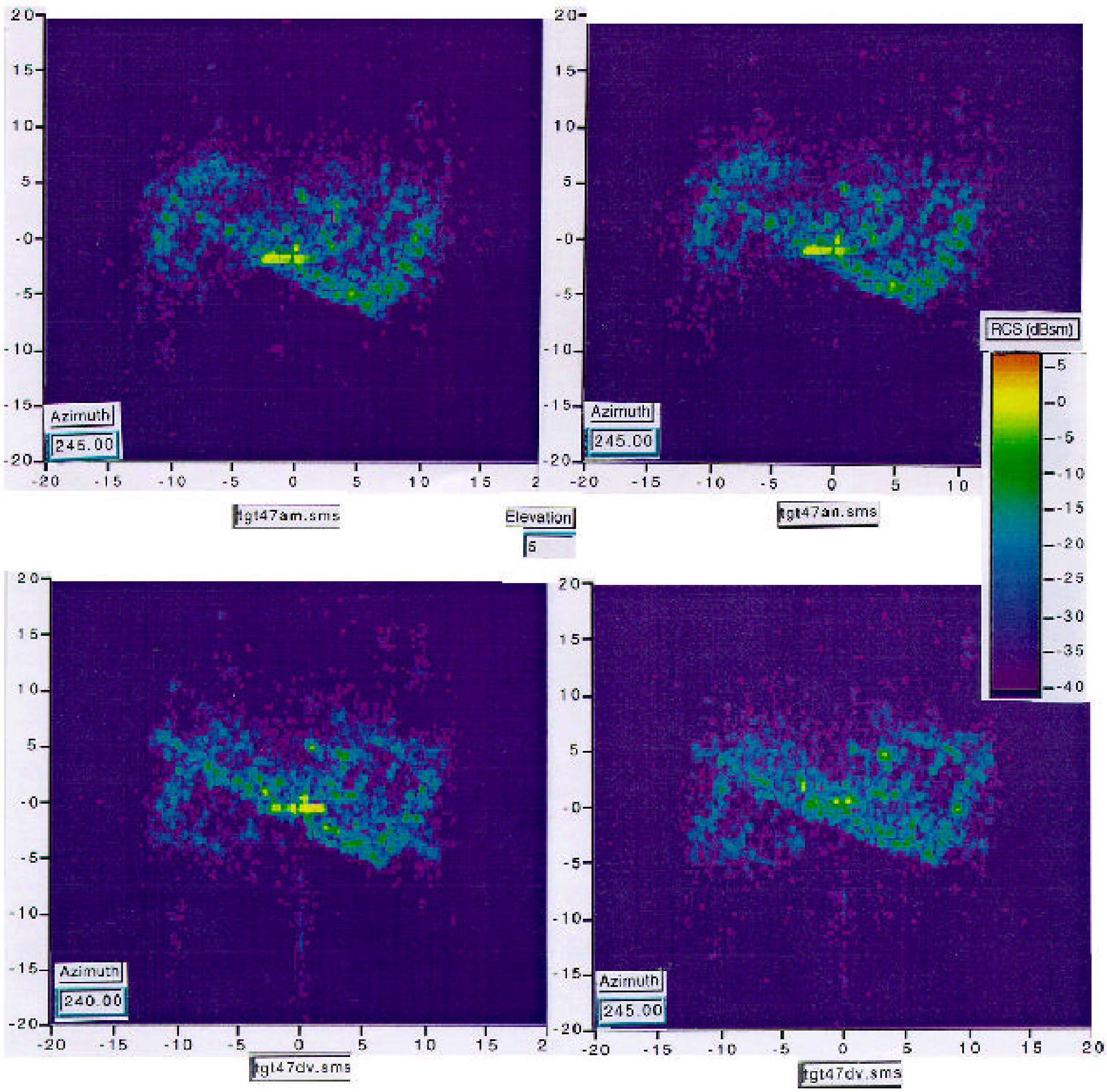

Figure 5. The Ka-Band VV ISAR of T-72 bumper #115 at 5° elevation, 240° and 245° azimuth.

Approaching azimuth 250°, displayed in Figure 5 is an elongated region of strong scattering, centered on a line askew of other vehicle borders. This scattering region was ascribed to interaction of the snorkel with the turret or side panel of the T-72/M1s. The elongated shape appearing for signature measurements tgt47ag, tgt47am, tgt47an, and tgt47cb of bumper #115 at an azimuth of 245° while

prevalent in tgt47cn, tgt47ct, tgt47dv and tgt47gc at an azimuth of 240° indicate the difference in ISAR images uncorrected for signature alignment.

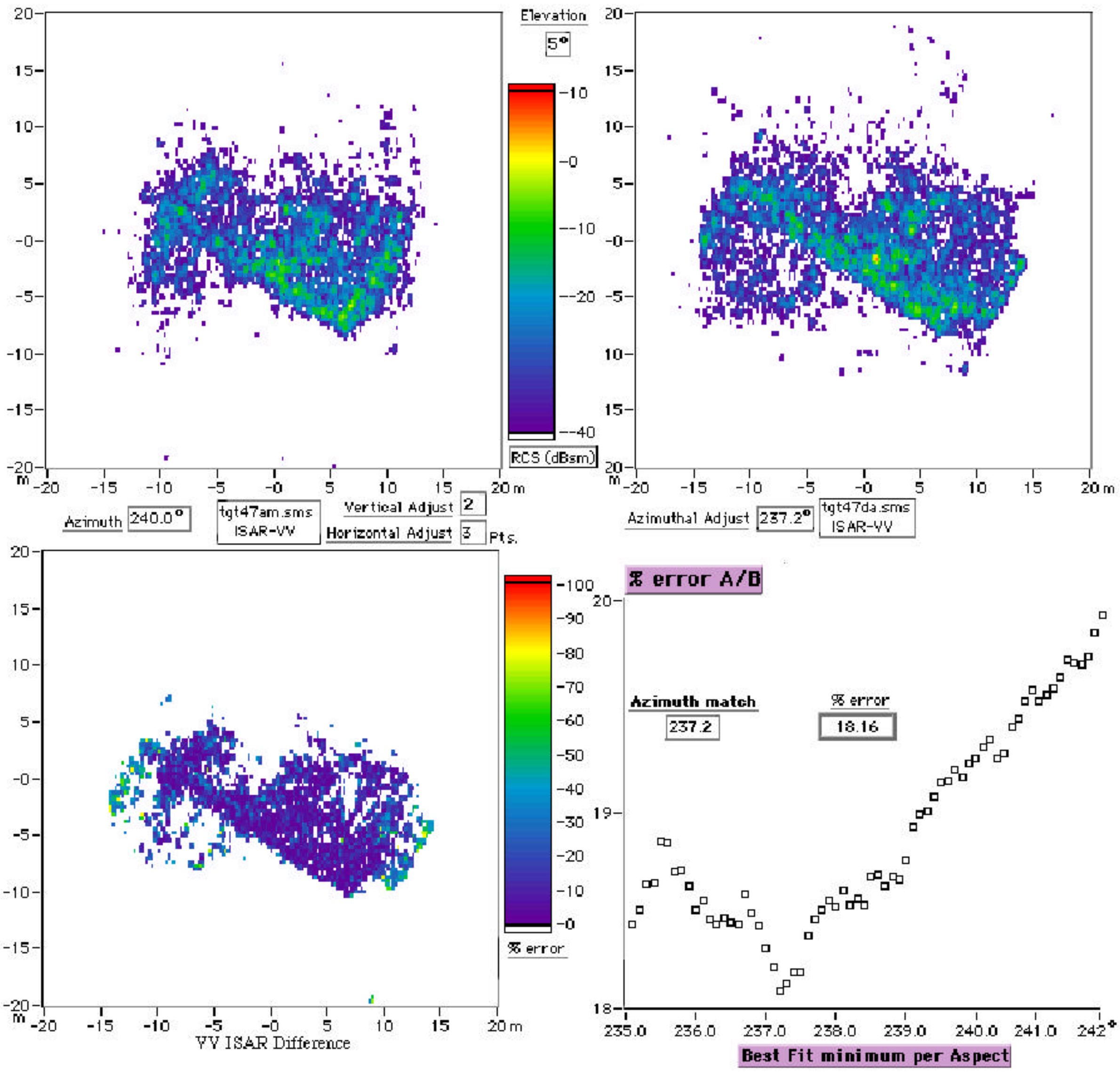

Figure 6. Optimization of the Ka-Band VV ISAR for the T-72 tanks with bumper #115 and bumper #197.

Further investigation of the configurational differences between the T-72 tanks was performed statistically using the 4th comparative level of evaluation. Expressed as the average point-to-point % difference between the T-72's ISAR imagery at 240° and 245° azimuth; Tables 10, 11 and 12 represent a goodness-of-fit cross-correlation summary between 105 images of the signature library. As with the RCS signature correlation procedure (level 2), azimuthal alignment, as well as vertical/horizontal adjustment,

was achieved by maximizing the correlation between images during the comparison procedure.

Exemplified in Figure 6 is an ISAR comparison of bumper #115 (upper left - tgt47am) and bumper #197 (upper right - tgt47da). Starting with the 240.0° azimuth image of T-72 #115, ISAR of the #197 were generated in 0.1° increments of azimuth until the average point-to-point % difference in RCS for the two images was minimized. The averaged % difference calculated for the image comparisons as a function of vehicle's azimuth is displayed on the lower right of Figure 6. Achieving an 18.2% minimum at 237.2° azimuth, the lower left of Figure 6 is a two-dimensional representation of the point-to-point % difference for the ISAR of the two T-72s. This false color representation enables one to clearly identify any mismatched scattering regions between the two vehicles. External fuel drums located on the rear of T-72 bumper #197 (but not present on bumper #115) generated a large mismatch between these images. Also observed as a mismatch (left on the % difference image) was a scattering region which might have been generated by multibounce between the tank and turntable.

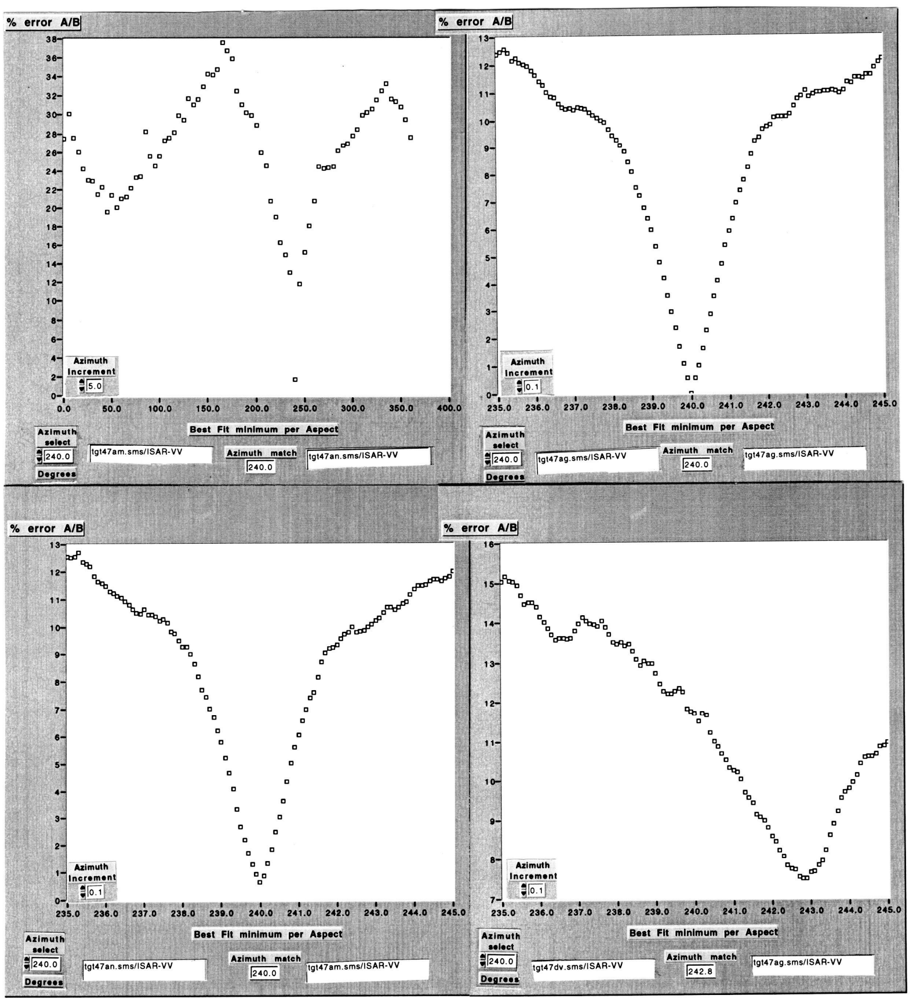

Figure 7. Optimization of the Ka-Band ISAR for the T-72 tank with bumper #115.

As the correlation of paired images from different vehicle configurations decreases, so does agreement between the azimuthal alignment established during the level 2 comparisons and the ISAR matching. For the T-72 images sited in Figure 6, the 240° azimuth image of bumper #115 best matched the 237.2° azimuth image of bumper #197. In conflict with the correction values of -1.9° and -1.1° calculated during the level 2 comparisons (a 0.8° difference as reflected in Table 1), the 2.8° difference in azimuth is caused by attempting to correlate images in which one image differs greatly in spatial extent (i.e. the external fuel drums). This argument becomes more evident when contrasted with the correlation of similar vehicles.

ISAR images at 5° intervals of azimuth for the T-72/M1 bumper #115 (tgt47an) were produced for the entire target spin to illuminate the behavior of the average point-to-point % difference algorithm as a function of image azimuth. As shown in Figure 7, by performing a comparison of tgt47an's image data to the 240° azimuth image of the tgt47am signature measurement; one observes a maximum(≈40%) average difference when the tanks are orthogonal and a ≈20% average difference when the tanks are facing in opposite directions. Performing a comparison of tgt47ag's 0.1° resolution images with its own 240° azimuth ISAR image produces a 4° well width perfectly centered at 240° with a 0% minima (upper right graph of Figure 7). This characteristic shape of the azimuth dependent % difference curve is also observed when correlating two images from two different, tightly controlled, turntable signature measurements of the same vehicle(lower left graph). Achieving an average difference of 0.7%, these two signature measurements (tgt47am and tgt47an) were acquired consecutively without driving the tank off the turntable.

More typical of the behavior observed when comparing ISAR images from different signature measurements of the same T-72 is shown in the lower right hand graph of Figure 7, evident by the 7.4% average value reflected in Tables 10 and 11. Note the close agreement between the 3.2° correction value calculated during the level 2 RCS signature comparisons and the minimum located at 242.8° azimuth. While the T-72 was driven off the turntable between acquisition of the AG and AM/AN signatures as well as the CN and CT signatures, these "day 1" and "day 2" target reference sets were acquired in a short time period (less than a few hours apart) relative to the remaining signature measurements of the reference vehicle (bumper #115) which accounts for the lower average % differences achieved.

Table 10. Statistical Comparison of Ka-Band VV ISAR for Eight Images of a T-72 at 240° Azimuth, 5° Elevation

	AG vs.	**AM vs.**	**AN vs.**	**CB vs.**	**CN vs.**	**CT vs.**	**DV vs.**
AM	2.3						
AN	2.5	0.7					
CB	8.1	8.1	8.1				
CN	8.3	8.4	8.5	7.7			
CT	8.1	8.2	8.1	8.4	4.1		
DV	7.5	7.3	7.4	7.3	8.1	7.6	
GC	9.6	9.4	9.1	9.3	8.9	9.1	7.3

The ISAR used for the comparisons cited in Tables 10, and 11, were generated from independent signature measurements of the same T-72 at 240° and 245° azimuth, respectively. An average 8.2% difference for all the values of each table except the four lowest (considered atypical of the measurements) is indicative of the value one should expect when performing a comparison between signatures from identical vehicle configurations. Typical of the vehicle-to-vehicle variations between the T-72/M1s, an average 10.5% difference (for the comparisons cited in Table 12 between the signature measurement tgt47au (bumper #000) versus the sixteen best fit images of bumper #115) indicates measurable configuration differences with these signature files. By correlating the ISAR images in which one vehicle differs greatly in spatial extent (i.e. a pair of rearward externally stowed fuel drums), the average % difference significantly increased to a value of 17.2% for comparisons of tgt47da (bumper #197) versus the eight best fit images of bumper #115. This value even dwarfed the 11.4% difference for tgt47fo bumper #292 ISAR versus the sixteen best fit images of T-72/M1 bumper #115 where bumper #292 was a T-72/B with the reactive armor removed (only the mounting studs remained).

Table 11. Statistical Comparison of Ka-Band VV ISAR for Eight Images of a T-72 at 245° Azimuth, 5° Elevation

	AG vs.	AM vs.	AN vs.	CB vs.	CN vs.	CT vs.	DV vs.
AM	2.6						
AN	2.6	0.7					
CB	8.8	8.6	8.7				
CN	8.6	8.5	8.6	7.2			
CT	7.3	7.4	7.4	7.5	4.4		
DV	8.1	8.6	8.4	8.1	7.1	7.1	
GC	9.1	8.9	9.1	10.1	8.3	8.5	7.3

Table 12. Statistical Comparison of Ka-Band VV ISAR for the T-72s at 240° and 245° Azimuth.

	@ 240° azimuth				@ 245° azimuth	
	AU vs.	DA vs.	FO vs.		AU vs.	FO vs.
AG	10.7	18.6	12.3	**AG**	11.2	12.5
AM	10.4	18.2	12.3	**AM**	11.1	12.5
AN	10.6	17.9	12.4	**AN**	10.9	12.3
CB	10.3	15.5	11.4	**CB**	11.2	10.9
CN	9.9	16.6	10.9	**CN**	10.2	10.9
CT	10.4	15.9	11.2	**CT**	9.9	10.8
DV	9.5	16.6	10.6	**DV**	10.4	10.2
GC	10.7	18.1	10.9	**GC**	11.2	10.6
AU		17.1	11.7			

Conclusion

For the purpose of this study, MMW signatures were acquired with the target and transceiver positioned in a near-field range configuration, $r \approx 150$m. This near field measurement configuration may compromise the signature base for training/re-programming ATR algorithms.[4] Far-field signatures are generally acquired with an incident wave front possessing a phase variation, $\Delta\varphi$, of $\pi/8$ or less across the target extent, d, as illustrated in Figure 8.[5] With an approximate phase variation of $\Delta\varphi \approx (2\pi/\lambda)(d^2/8r)$, the far-field range criterion becomes $r \geq 2 \ d^2/\lambda$. However, strong arguments can be made for utilizing this Ka-band signature database library for the development and functional demonstration of new recognition algorithms.

At all four levels of comparing the signatures from the eleven T-72 tanks, the statistical variations observed in this database were consistent with configurational differences documented during on-site inspections of the vehicles, as well as the signature acquisition sequence executed over the three day measurements period. Considered the most complete Ka-band radar signature library currently available on the T-72 (and perhaps on any single type of vehicle), signatures were acquired from tanks in a variety of physical conditions (including a parade version). The inclusion of signatures from the T-72/B with and without the reactive armor in place expands the usefulness of this signature library.

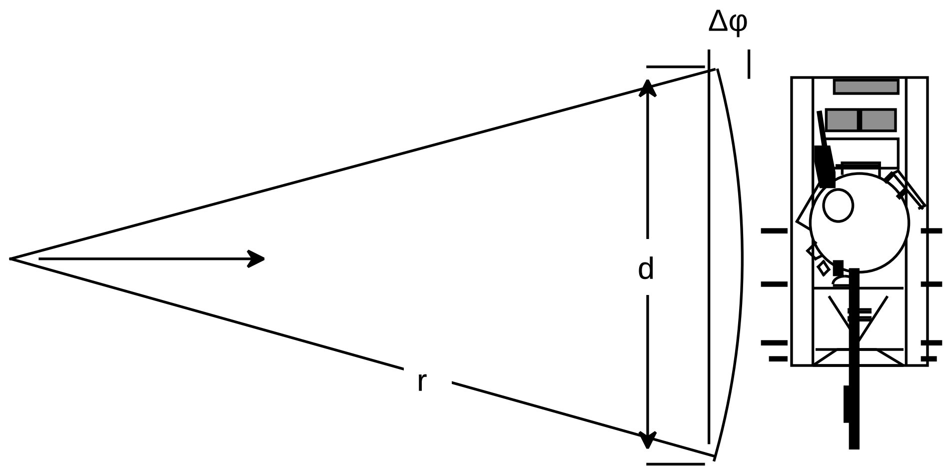

Figure 8. Phase variation of the incident wave front over the target extent.

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